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Incompatible trace element transport in phosphorus enriched peridotitic mantle across the upper to lower mantle boundary

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Progressive dehydration of subducting oceanic lithosphere with increasing pressure and temperature results in release of incompatible trace elements and halogen-rich fluids that infiltrate the mantle wedge and drive metasomatism over a broad depth range. Apatite is common in metasomatic assemblages of mantle wedge peridotites and mélange zones, indicating that phosphorus is a significant component of the trace element flux into the wedge. With progressive subduction, tuite [γ-$Ca_3(PO_4)_2$] forms from apatite at depths of ~220-230 km and ~250-280 km in peridotitic and basaltic lithologies respectively, thereby replacing apatite as phosphorus-saturating phase and major carrier of Y+REE, LILE, U and Th.

Across the upper-to-lower mantle boundary, major phosphorus and/or LREE carriers such as majoritic garnet and ringwoodite vanish, while new hosts for LILE–LREE–HFSE (e.g., davemaoite, K-hollandite) emerge. However, experimental constraints on incompatible trace element partitioning in Ca-phosphate–bearing assemblages at these conditions are lacking.

This study addresses upper-to-lower mantle trace element fluxes by (1) determining incompatible trace element concentrations in tuite and coexisting phases within a peridotitic bulk composition at pressures that straddle upper-to-lower mantle transition and by (2) assessing the role of tuite in trace element storage and transport across this boundary.

Multi-anvil experiments were conducted at 15–25 GPa and 1600-2000°C on a moderately fertile peridotite doped with 3 wt% synthetic β-$Ca_3(PO_4)_2$, approximately 2200 µg/g each of Cl and Br, and 1 wt% of a trace-element mix.

Results show that in P-poor peridotites, in which phosphorus saturation in silicate phases cannot be maintained to lower mantle depth, clinopyroxene and majoritic garnet dominate trace element storage and transport across the tuite stability gap. In P-rich peridotites tuite forms from apatite and remains stable to the upper-to-lower mantle boundary. Here, apatite and tuite are the principal hosts of REE, LILE, U, and Th at pressures below the davemaoite stability field. Coexisting clinopyroxene and (majoritic) garnet host only subordinate LREE and Y+HREE, respectively. Upon entry into the lower mantle, tuite formed from apatite or via majoritic garnet breakdown, is expected to resume a major role in trace element transport, second only to davemaoite.